Saskatchewan
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Trout Cage Culture and Water Quality in Besnard Lake

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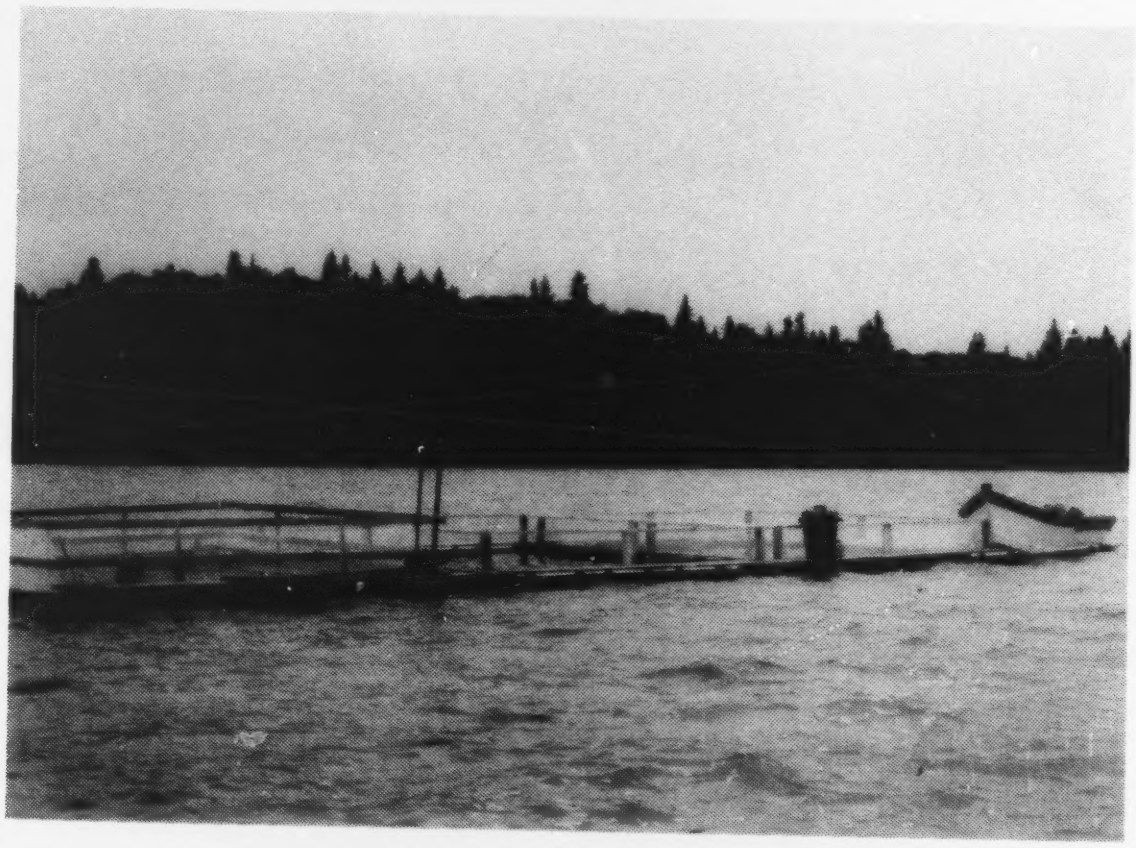

TROUT CAGE CULTURE AND WATER QUALITY IN BESNARD LAKE

by

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FISHERIES TECHNICAL REPORT 88-3

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EXECUTIVE SUMMARY

SITUATION

A great deal of interest in cage culture of trout has recently developed in Saskatchewan. In 1987, a total of about 26 200 kg of marketable rainbow trout were produced from 19 locations. Most cage culture activities have concentrated in central and northern Saskatchewan, where most lakes are in an oligotrophic or mesotrophic condition.

Intensive cage culture operations can have adverse impacts on the aquatic environment. Recognizing this, the Fisheries Laboratory of the Fisheries Branch undertook a preliminary water quality monitoring program on Besnard Lake in the summer of 1987. An intensive trout cage culture operation was being conducted there, on an experimental basis, under the Saskatchewan Indian Agricultural Program. In May, a total of 50 000 rainbow trout fingerlings were stocked into floating cages located in a small bay in the west basin of Besnard Lake. In October, an estimated 44 000 fish weighing 8.8 tonnes were produced from the operation.

Between June 10 and August 26, 1987 a number of water quality related variables were monitored from the cage culture site and a reference bay.

The purpose of the study was to examine certain water quality variables for the development of workable water quality guidelines for cage culture in Saskatchewan.

RESULTS

The most salient and immediate effect of the cage culture operation on Besnard Lake was an increase in water turbidity, which could be measured most sensitively in terms of underwater light extinction coefficients and less sensitively with Secchi disc transparency.

The higher water turbidity at the culture site could be attributable to the presence of significantly more suspended particulates (primarily detritus and phytoplankton) in the water. Intensive cage culture operations are known to provide an abundant supply of particulate matter from unconsumed feed, and faecal material from the fish.

The maximum chlorophyll *a* concentration of 19.60 mg/m^3 suggests that Besnard Lake is already mesotrophic and, at times, may even be eutrophic. Its calculated average annual total phosphorus concentration (40 mg/m^3) has already exceeded the maximum allowable concentration of 30 mg/m^3 recommended, in the recently approved Saskatchewan Aquaculture Policy, for lakes that may be used for cage culture purposes.

An estimated 156 kg of phosphorus was discharged from the cage culture site during first year of operation. The impact of this additional phosphorus input on the west basin of Besnard Lake may not be

significant, but it can be quantified in terms of certain water quality parameters: as a result of the first year of operation, average annual concentration of total phosphorus would be expected to increase from the present level of 40 mg/m³ to 42 mg/m³; annual mean and maximum chlorophyll concentrations from 6.7 mg/m³ and 19.60 mg/m³ to 7.3 mg/m³ and 20.70 mg/m³, respectively. The chances of the basin being eutrophic will increase from 41% to 48%, whereas its chances of staying mesotrophic will diminish from 59% to 52%.

Allowing a 5% increase in total phosphorus concentration over the pre-culture level, the carrying capacity of the west basin of Besnard Lake is estimated to be 11.5 tonnes, which is close to the first year's production.

The level of eutrophication expected to result from the cage culture operation may benefit the fishery of Besnard Lake, but the overall increase in fish yield would be negligible.

Large uncertainties may be associated with use of water quality management models developed with data obtained elsewhere. The risk of obtaining erroneous estimates is further increased if low quality input data are used. Therefore, in order to detect actual changes in the aquatic environment, periodic monitoring programs are needed in connection with cage culture operations.

Based on the findings of the study, it is recommended that:

Periodic monitoring programs be conducted in conjunction with cage culture operations; parameters monitored should include: status of

native fish populations, plankton, chlorophyll, temperature and oxygen profiles, pH, Secchi disc transparency, and plant nutrients;

Maximum concentration of chlorophyll *a* should be used as a primary input datum for estimations of total phosphorus input and carrying capacity of lakes; and

Intensive cage culture in the west basin of Besnard Lake may be allowed to continue with the carrying capacity set at 12 tonnes of marketable rainbow trout; furthermore, monitoring programs such as mentioned above should be conducted in 1989 and again in 1992.

ACKNOWLEDGEMENTS

I would like to thank J. Matthews and G. Sedgewick for assisting with field and laboratory work, C. Schurr for typing the manuscript and J. Merkowsky for drafting the figures.

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TABLE OF CONTENTS

	Page
EXECUTIVE SUMMARY	i
ACKNOWLEDGEMENTS	v
LIST OF TABLES	vii
LIST OF FIGURES	viii
1. INTRODUCTION	1
2. THE LAKE	1
3. MONITORING SITES	2
4. METHODS	4
5. RESULTS	5
5.1 Physical Parameters	5
5.2 Plant Nutrients	9
5.3 Plankton	12
5.3.1 Phytoplankton	12
5.3.2 Netplankton	17
5.4 Macrobenthos	23
6. DISCUSSION	24
6.1 Between Station Differences in Measured Variables	24
6.2 Impact of Cage Culture on Water Quality	27
7. CONCLUSIONS AND RECOMMENDATIONS	34
8. LITERATURE CITED	36
9. APPENDICES	38

LIST OF TABLES

Page

1. Concentrations (mg/L) of plant nutrients in Besnard Lake, 1987. 11

2. Simple correlation matrix of water turbidity related variables (both stations 1 and 2 combined), Besnard Lake, 1987. 26

LIST OF FIGURES

Page

1. Map of Besnard Lake showing locations of study sites. 3

2. Temperature and dissolved oxygen levels at stations 1 and 2 in Besnard Lake, 1987. 7

3. Integrated water column pH at stations 1 and 2 in Besnard Lake, 1987. 8

4. Light extinction coefficient and Secchi depth at stations 1 and 2 in Besnard Lake, 1987. 10

5. Abundance of Bacillariophyceae at stations 1 and 2 in Besnard Lake, 1987. 13

6. Abundance of Euglenophyceae at stations 1 and 2 in Besnard Lake, 1987. 14

7. Phytoplankton composition at stations 1(A) and 2(B) in Besnard Lake, 1987. 15

8. Abundance of phytoplankton at stations 1 and 2 in Besnard Lake, 1987. 16

9. Concentrations of chlorophyll a at stations 1 and 2 in Besnard Lake, 1987. 18

10. Zooplankton composition at stations 1(A) and 2(B) in Besnard Lake, 1987. 19

11. Abundance of zooplankton at stations 1 and 2 in Besnard Lake in 1987. 21

12. Weight of netplankton (A) and amount of organic detritus (B) at stations 1 and 2 in Besnard Lake, 1987. 22

1. INTRODUCTION

Recently, a great deal of interest has developed in trout cage culture in Saskatchewan. In 1987, a total of 105 000 rainbow trout (weighing 23 600 kg) were produced from 11 locations (Horner 1988). Most cage culture activities have concentrated in central and northern Saskatchewan where most lakes are in an oligotrophic or mesotrophic condition.

Intensive cage culture operations can have adverse impacts on the aquatic environment (Beveridge 1984, Hakanson 1986, Penczak, et al. 1982). Recognizing this, the Saskatchewan Fisheries Laboratory of the Fisheries Branch undertook a preliminary water quality monitoring program in the summer of 1987 on Besnard Lake where intensive trout cage culture was being conducted, on an experimental basis, under the Saskatchewan Indian Agricultural Program.

The purpose of the study was to examine certain water quality variables for the development of workable water quality guidelines for cage culture in Saskatchewan.

2. THE LAKE

Besnard Lake (Lat. 55°25', Long. 106°00') is located in central Saskatchewan about 50 km west of Lac la Ronge. It is accessible by a logging road (33 km) which connects to Highway 165.

Besnard Lake has a water area of 177 km^2 and a volume of 1.4 x $10^9 m^3$. Its mean and maximum depths are 7.9 m and 26.7 m, respectively

(Chen 1974). The lake has a watershed area of approximately 806 km² (determined from 1:250 000 topographic map sheets 73O and 73N).

The water in Besnard Lake contains 60 mg/l total dissolved solids, 50 mg/l bicarbonates, 15 mg/l calcium, 4 mg/l magnesium, and 42 mg/l total alkalinity (as calcium carbonate). The standing crop of netplankton was determined to be 64 kg/ha (dry weight) and that of the macrobenthos was 97 kg/ha (wet weight) (Chen 1974).

Besnard Lake supports a commercial as well as a recreational fishery. Commercial production averaged 26 240 kg/yr in the past 46 years (1925-1987). Whitefish, walleye and pike are the major species harvested.

Besnard Lake is divided into two distinct basins (west and east) by a narrows. The present study is concerned mainly with the shallower, smaller west basin. It has a water area of 38 km², a volume of 281 x 10^6 m³, a mean depth of 7.4 m and a watershed area of 486 km².

3. MONITORING SITES

The cage culture site (station 1) was located in a small bay about 2 km east of the Mercer River inlet (Fig. 1). A total of 50 000 rainbow trout fingerlings were stocked into floating cages (each measuring 4.9 m x 4.9 m x 3.0 m) in May and fed commercial trout feeds over the summer. The number of cages used was five initially, but was increased to 10 in mid-July (Ivanochko 1987).

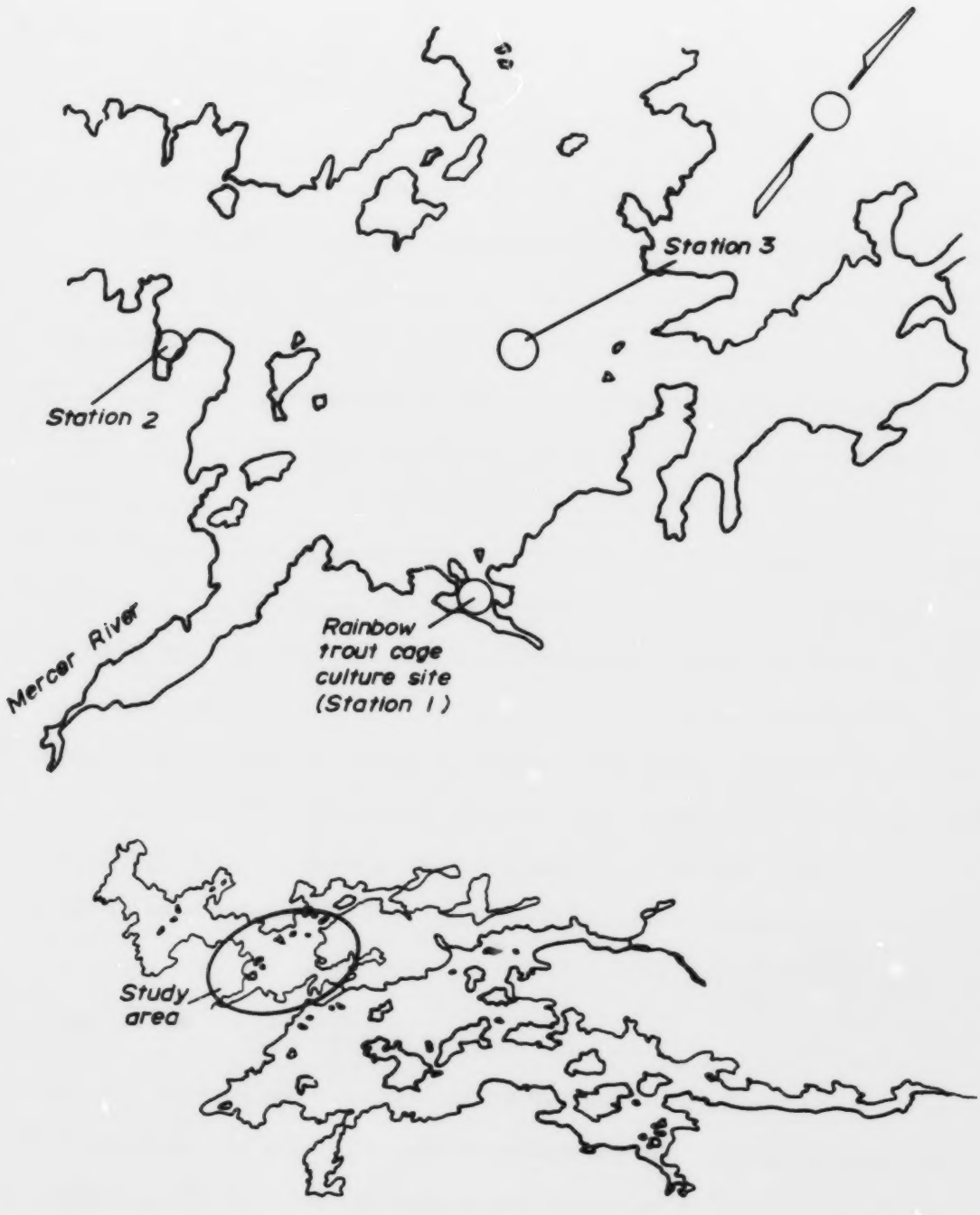


Fig. 1 Map of Besnard Lake showing locations of study sites.

Another small bay, about 2 km west of the Mercer River inlet, was chosen as a reference site (station 2, Fig. 1). This bay is approximately the same size and depth as the one used for the cage culture. In addition, a third location in the open water area (station 3, Fig. 1) was monitored mainly for deep water temperature and dissolved oxygen profiles.

These sites were monitored for selected water quality parameters seven times between June 10 and August 26, 1987.

4. METHODS

A YSI model 57 oxygen meter was used to monitor oxygen and temperature profiles. Light attenuation in the water column at every 0.5 m, was recorded with an under water light meter (Protomatic photometer). A 20 cm diameter all white Secchi disc was used to measure water transparency. The equation $\ln I_z = \ln I_o - kZ$, was used to calculate the extinction coefficient, k; where I_o and I_z are light intensities at surface and depth z, respectively.

Integrated (mixed) water samples (each 2.5L) were obtained with a 0.5-L capacity Kemmerer water sampler from 0 (just below surface), 1.0, 1.5, 2.0 and 2.5 m for nutrient, phytoplankton and chlorophyll determinations. A portable pH meter was used to measure the pH of surface, bottom and integrated water samples in the field.

Samples for chlorophyll determinations were vacuum filtered in the field with glassfibre filters. The filters with the retained

samples were kept frozen until analysis. Methanol was used to extract the pigments (Holm-Hansen 1978).

The water samples for nutrients analysis were preserved with 10 ml concentrated H_2SO_4 immediately after collection. They were stored at room temperature before being analyzed by the Saskatchewan Research Council for nitrogen and phosphorus.

Water samples for phytoplankton enumerations were fixed immediately after collection with 20 ml Lugol's solution. Enumerations were done with the sedimentation tube-inverted microscope method.

Water samples for netplankton standing crop determinations were collected with a Rawson plankton trap from depths 0-0.5 m, 1-1.5 m and 2-2.5 m; the trap was 0.5 m long and had a capacity of 10 L. The water collected was filtered through a Wisconsin-type plankton net made of No. 20 bolting silk. The concentrated samples were preserved in 5% formaldehyde.

Comparisons of measurements from the cage culture and the reference sites were done mainly by 2-way ANOVA.

5. RESULTS

5.1 Physical Parameters

Measurements of temperature and concentrations of dissolved oxygen from surface to bottom at the three sites are presented in Appendix 1, and those of the pH, light extinction coefficient and Secchi disc transparency are in Appendix 2.

Maximum surface water temperature of 22.0°C was recorded at the end of July. Vertical temperature changes were gradual, and a thermocline did not exist even at the deep (15.5 m) water station (station 3). The maximum difference between surface and bottom (3 m) temperatures at stations 1 and 2 varied between 0.2 and 1.5°C with an average of 0.5°C. Changes in the average water column temperatures and dissolved oxygen concentrations at these two stations are shown in Fig. 2.

Concentrations of dissolved oxygen also declined gradually with depth, reaching very low levels only in the bottom water. Average concentrations of dissolved oxygen in the entire water column at stations 1 and 2 were high throughout the summer (Fig. 2). No significant differences were found in dissolved oxygen levels and temperatures between the cage culture and the reference sites.

The water in Besnard Lake is alkaline. Values of pH at stations 1 and 2 varied from 7.90 to 9.09 during the summer. There is little difference between the surface and bottom pH values in the shallow stations, but the one determination from station 3 suggests that the difference could be more than one unit between surface and deep waters (Appendix 2). Values of the pH in the integrated water samples from stations 1 and 2 are illustrated in Fig. 3. The values at station 2 appear to be higher than at station 1, but the differences were not statistically significant ($p>0.06$).

Secchi depths varied from 1.5 to 2.38 m at station 1 with a mean of 2.04 m, and from 1.42 to 3.0 m at station 2

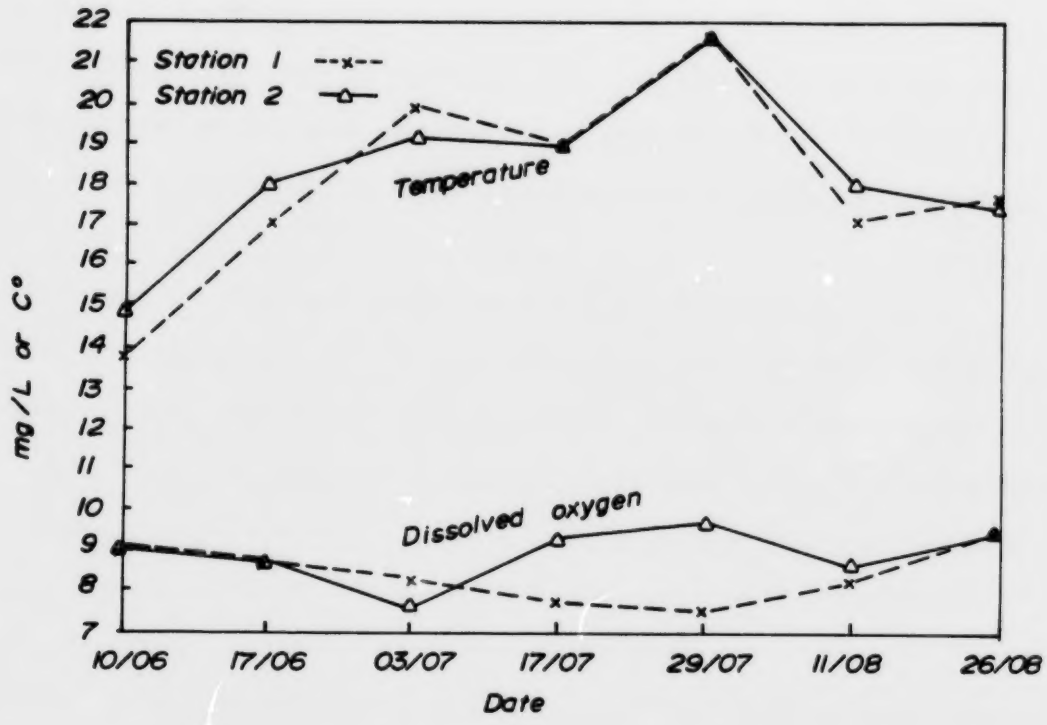


Fig. 2 Temperature and dissolved oxygen levels at stations 1 and 2 in Besnard Lake, 1987.

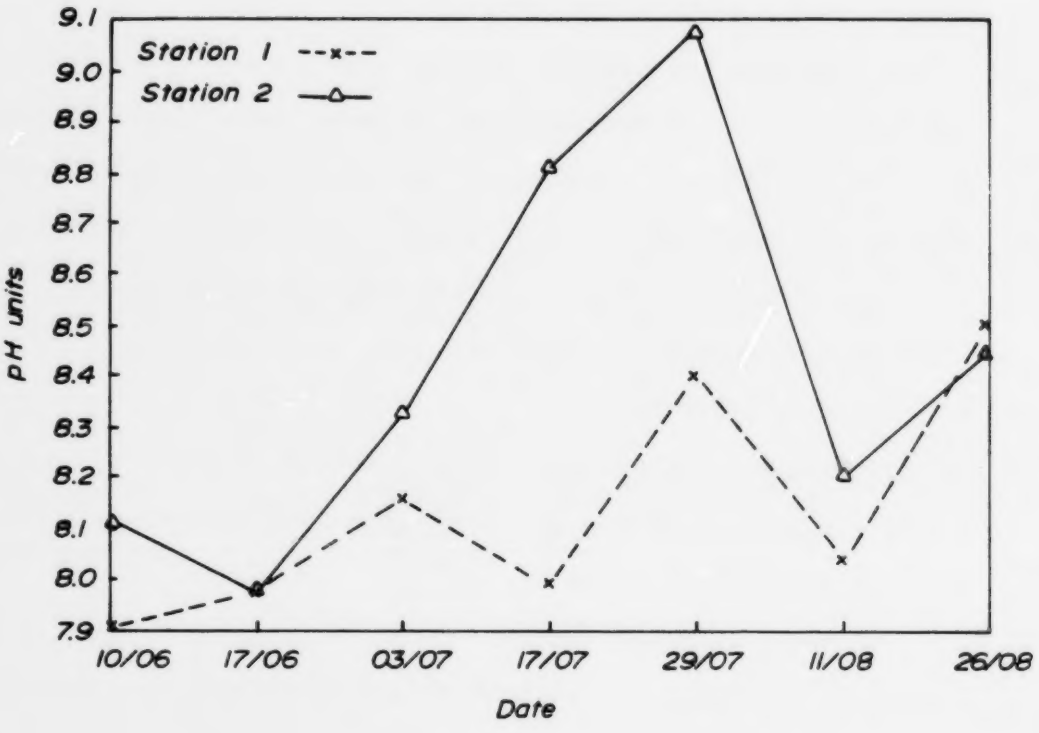


Fig. 3 Integrated water column pH at stations 1 and 2 in Besnard Lake, 1987.

with an average of 2.27 m. As shown in Fig. 4 Secchi depths changed significantly ($p<0.001$) with sampling dates, becoming much smaller as the summer progressed. However, there was not a significant difference between the two stations ($p>0.07$).

Contrary to Secchi depths, under water light extinction coefficients (the exponential rates of under water light attenuation relative to surface irradiance) increased significantly ($p<0.001$) towards the latter part of the summer. Significantly ($p<0.001$) more light was available underwater in the reference bay (station 2) than in the water just outside the cages (Fig. 4).

5.2 Plant Nutrients

Concentrations of major plant nutrients at stations 1 and 2 did not vary significantly throughout the summer, and measurements from both stations were similar (Table 1).

Ammonia nitrogen varied between 0.04 to 0.1 mg/L with an average of 0.07 mg/L for station 1 and 0.06 mg/L for station 2. Concentrations of nitrate and nitrite nitrogen were usually low, ranging from below the detection limit of 0.005 mg/L to 0.06 mg/L with a mean value of <0.02 mg/L. Total Kjeldhal nitrogen (measures both ammonia and organic nitrogen) varied between 0.25 and 0.76 mg/L with averages of 0.48 mg/L and 0.55 mg/L for stations 1 and 2, respectively.

Concentrations of total phosphorus fluctuated between 0.03 and 0.08 mg/L with an average of 0.05 mg/L in both stations.

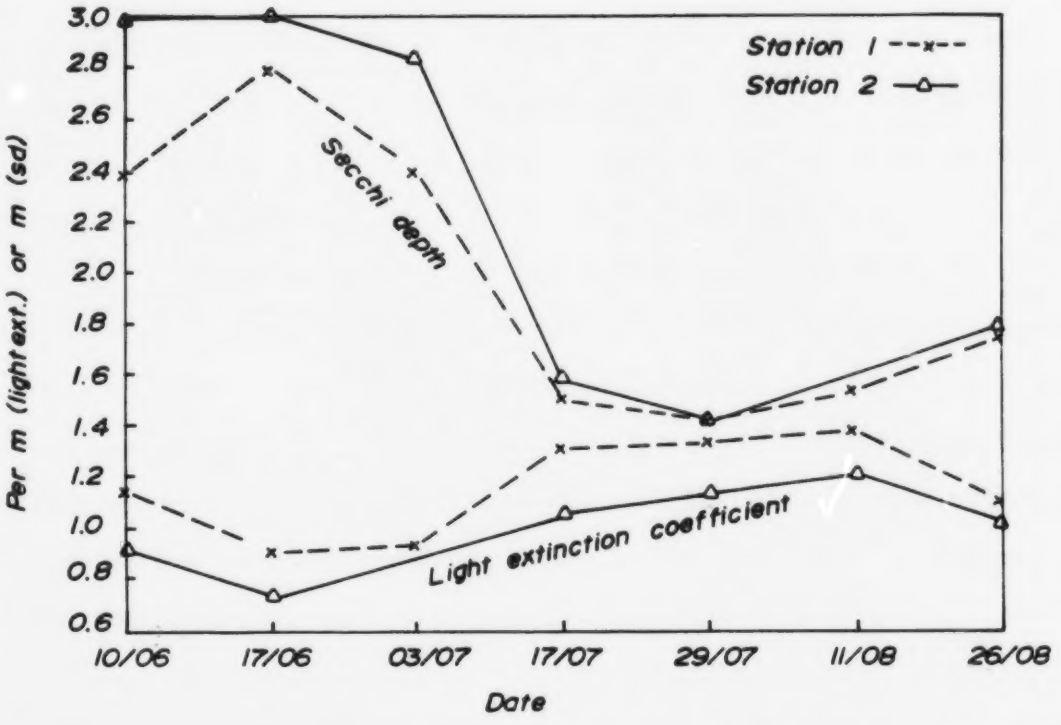


Fig. 4 Light extinction coefficient and Secchi depth at stations 1 and 2 in Besnard Lake, 1987.

Table 1. Concentrations (mg/L) of plant nutrients in Besnard Lake, 1987.

Date	Station 1				Station 2			
	NH3 N	NO2+NO3 N	Kjeld N	Tot-P	NH3 N	NO2+NO3 N	Kjeld N	Total-P
10/06	0.11	0.06	0.42	0.05	0.06	0.006	0.44	0.05
17/06	0.05	0.009	0.55	0.04	0.06	0.008	0.52	0.05
03/07	0.07	0.006	0.68	0.05	0.06	0.006	0.44	0.03
17/07	0.06	0.005	0.36	0.07	0.07	0.005	0.43	0.04
29/07	0.1	0.06	0.76	0.05	0.04	0.07	0.66	0.04
11/08	0.09	0.005	0.25	0.05	0.08	0.005	0.63	0.08
26/08	0.04	0.005	0.35	0.05	0.04	0.005	0.71	0.04
Average	0.07	0.02	0.48	0.05	0.06	0.02	0.55	0.05

5.3 Plankton

5.3.1 Phytoplankton

A list of the phytoplankton species found at stations 1 and 2 is presented in Appendix 3. Among the major groups of phytoplankton found, the blue-green algae (Myxophyceae) were dominant throughout the season, with *Microcystis aeruginosa* being the most abundant species, followed by *Coelosphaerium* spp and *Aphanizomenon flos-aquae*. Among the green algae (Chlorophyceae), *Pediastrum* spp , *Scenedesmus* spp, *Dictyosphaerium simplex* and *Oocystis borgei* were dominant. *Melosira granulata* was the most abundant diatom, followed by *Fragilaria crotonensis*, *Asterionella formosa* and *Stephanodiscus astrea*. From Fig. 5 and 6, there appeared to be more diatoms and euglenoids occurring at station 1 than at station 2, but the differences were not statistically significant ($p>0.07$).

Relative abundance of the various phytoplankton groups on a seasonal basis is presented in Fig. 7A and 7B: both stations were similar.

Figure 8 illustrates changes in standing crop of the phytoplankton at both stations. Abundance of the phytoplankton increased steadily in both stations as summer progressed, reaching maxima around the middle of August. The seasonal mean of the phytoplankton standing crop was 95 cells/ml ± 23 cells/ml (SD) for station 1, and 94 cells/ml ± 18 cells/ml (SD) for station 2. There was not a significant difference between the two stations.

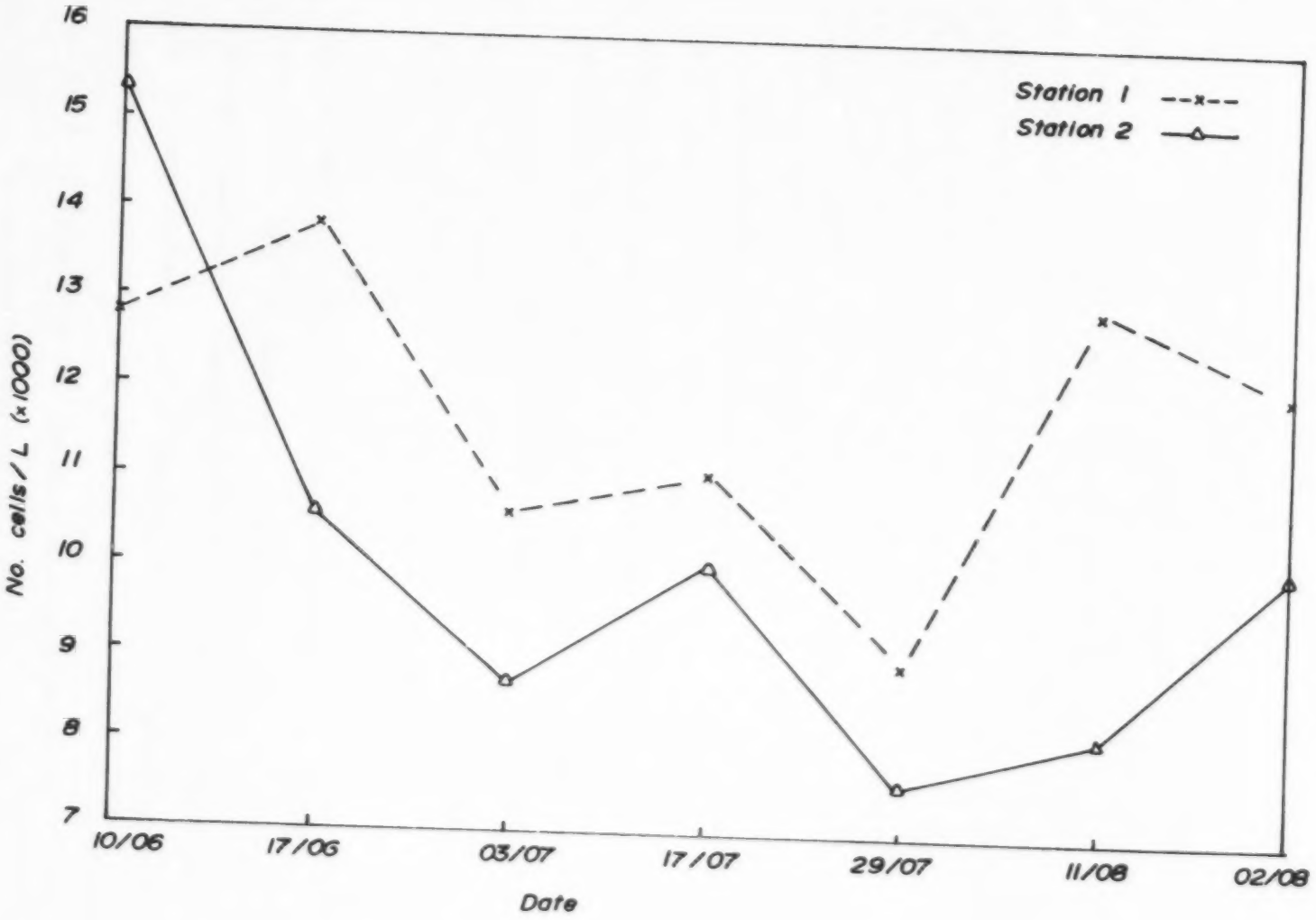


Fig. 5 Abundance of Bacillariophyceae at stations 1 and 2 in Besnard Lake, 1987.

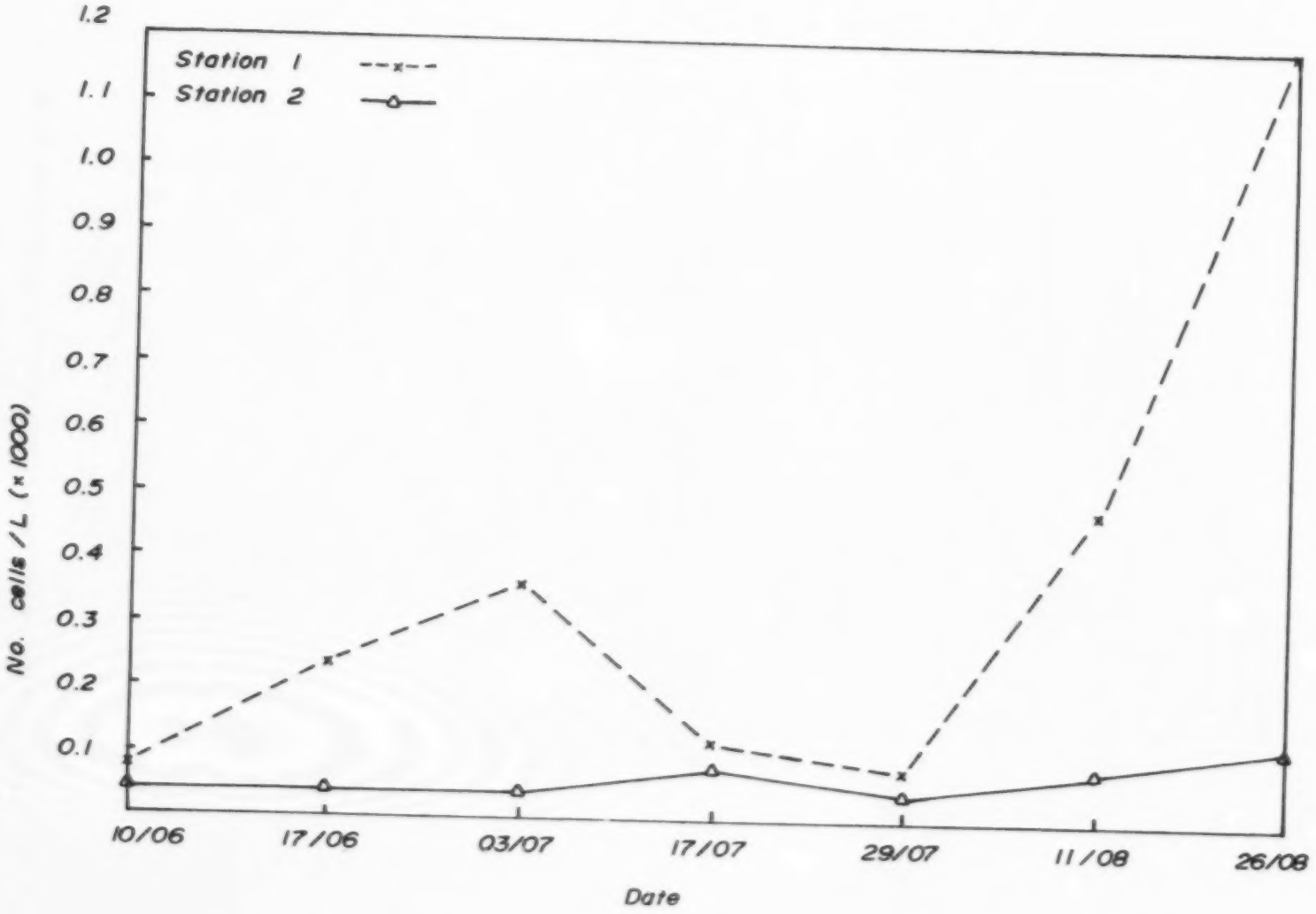


Fig. 6 Abundance of Euglenophyceae at stations 1 and 2 in Besnard Lake, 1987.

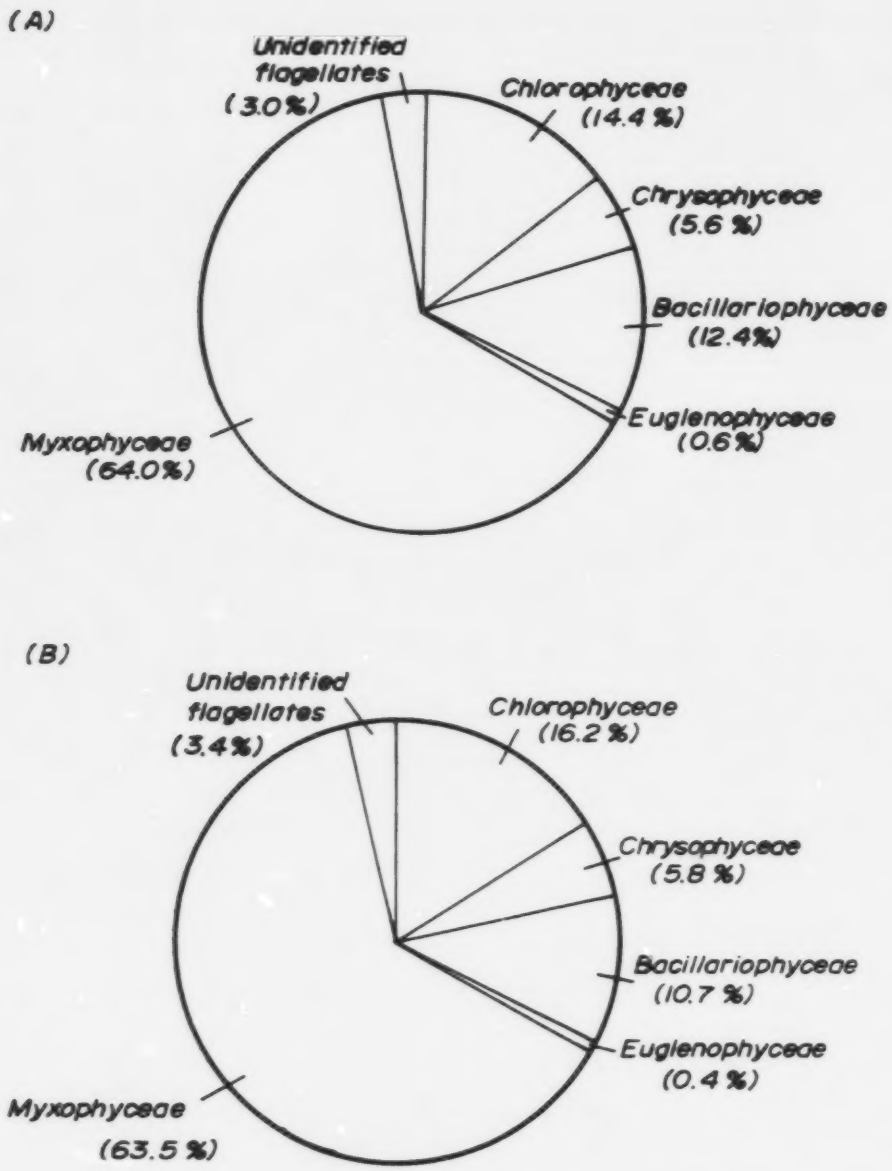


Fig. 7 Phytoplankton composition at stations 1 (A) and 2 (B) in Besnard Lake, 1987.

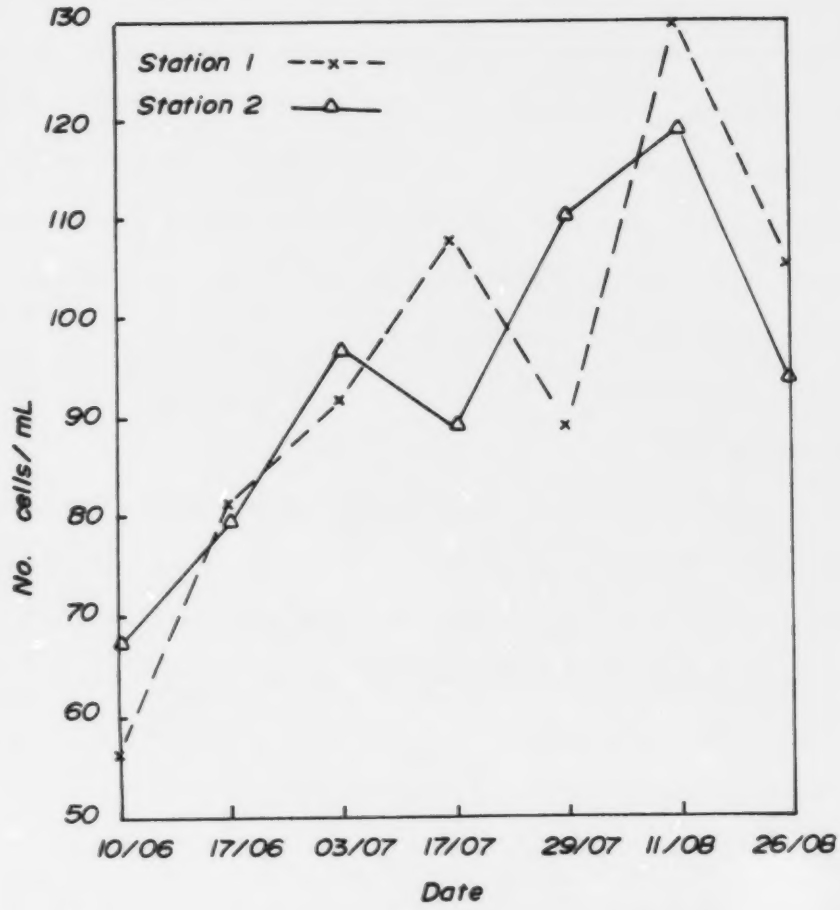


Fig. 8 Abundance of phytoplankton at stations 1 and 2 in Besnard Lake, 1987.

Concentrations of chlorophyll *a* (corrected for pheopigments) varied from 2.67 mg/m³ to 19.6 mg/m³ (average 10.11 mg/m³ ± 5.62 mg/m3), at station 1. They ranged between 1.34 mg/m³ and 19.6 mg/m³ (average 9.16 mg/m³ ± 7.09 mg/m³) at station 2 (Fig. 9). Chlorophyll concentrations differed significantly ($p<0.02$) between sampling dates, but not between stations ($p>0.6$). The occurrence of maximum chlorophyll concentrations coincided roughly with that of maximum phytoplankton standing crop.

5.3.2 Netplankton

Zooplankton

The result of zooplankton enumerations is presented in Appendix 4. Relative importance of the major groups of zooplankton on a seasonal basis is illustrated in Fig. 10A and 10B. Rotifers were by far the most abundant zooplankters, making up 89% (station 1) and 80% (station 2) of the seasonal total counts. Keratella cochlearis was the most dominant rotifer, followed by Polyarthra, Kellicottia longispina, Monostyla and Trichocerca. The nauplii of copepods, were also abundant throughout the summer, accounting for 7% and 10% of the seasonal averages respectively for stations 1 and 2.

With respect to larger zooplankters, there were relatively more cladocerans at station 2 (7%) than at station 1 (1%) while the relative abundance of copepods was about the same at both stations (4%).

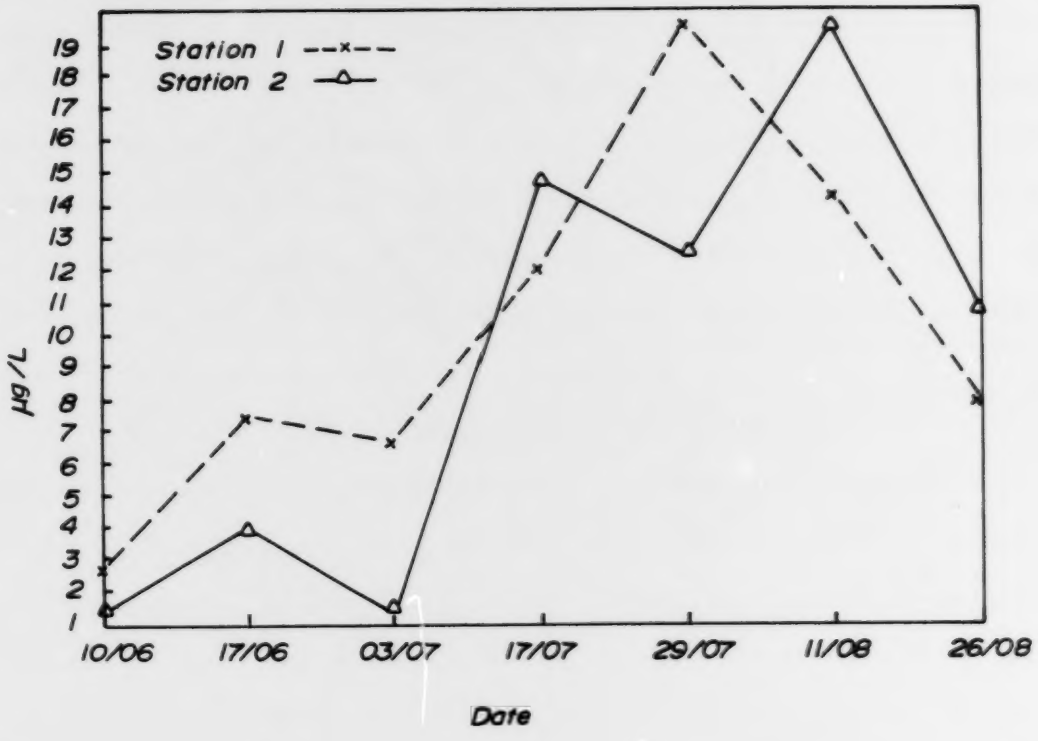


Fig. 9 Concentration of chlorophyll a at stations 1 and 2 in Besnard Lake, 1987.

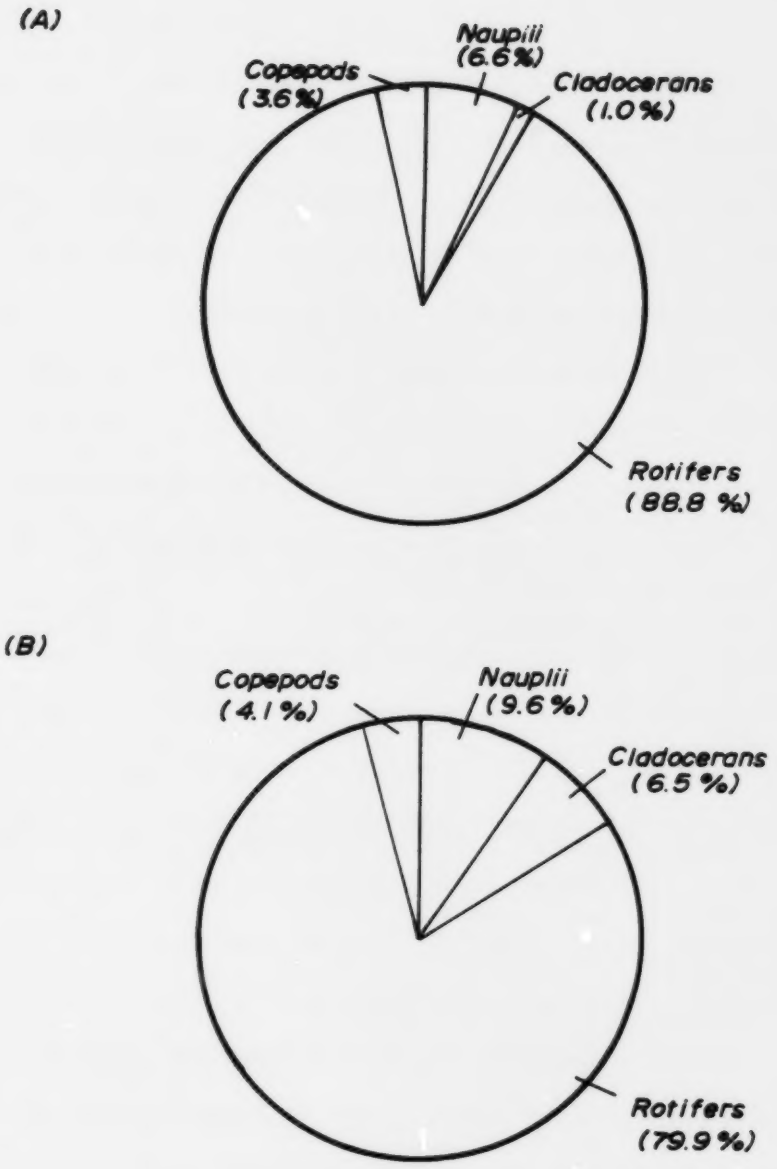


Fig. 10 Zooplankton composition at stations 1 (A) and 2 (B) in Besnard Lake, 1987.

Changes in total zooplankton counts in the summer are shown in Fig. 11. After the abrupt drop in abundance from the initial peaks in early summer there were no significant changes in densities over the summer ($p>0.1$). Total zooplankton concentrations at station 1 varied between 340 and 1590 organisms/L (mean ± SD, 658 ± 465 organisms/L), and those at station 2 varied from 284 to 621 organisms/L (mean ± SD, 354 ± 135 organisms/L). Although concentrations at station 1 appeared to be consistently higher than those at station 2, the difference between station means was not statistically significant ($p>0.07$).

Dry weights of the netplankton varied from 5.9 mg/L to 9.3 mg/L (mean ± SD, 8.4 ± 1.6 mg/L) at station 1, and from 3.4 mg/L to 10.5 mg/L (mean ± SD, 6.3 ± 2.6 mg/L) at station 2. Concentrations of organic matter (measured as loss on ignition) in the netplankton ranged from 1.3 mg/L to 4.6 mg/L (mean ± SD, 3.1 ± 1.2 mg/L) for station 1, and from 1.0 to 7.9 mg/L (mean ± SD, 2.5 ± 2.7 mg/L) for station 2 (Fig. 12A). Although all but one measurement from station 1 were greater than those from station 2, no significant differences were found between the two stations ($p>0.06$).

Detritus

Besides plankton, netplankton samples always contain certain amounts of detritus. The amorphous detritus in the Besnard Lake netplankton samples consisted mainly of organic matter. The size of the detritus clumps varied from 0.11 mm^2 to 3.33 mm^2 (average 0.87 mm^2) at station 1, and from 0.11 mm^2 to 2.66 mm^2 (average 0.51 mm^2) at station 2. The abundance of detritus varied between 0.78 mm^2/ml and

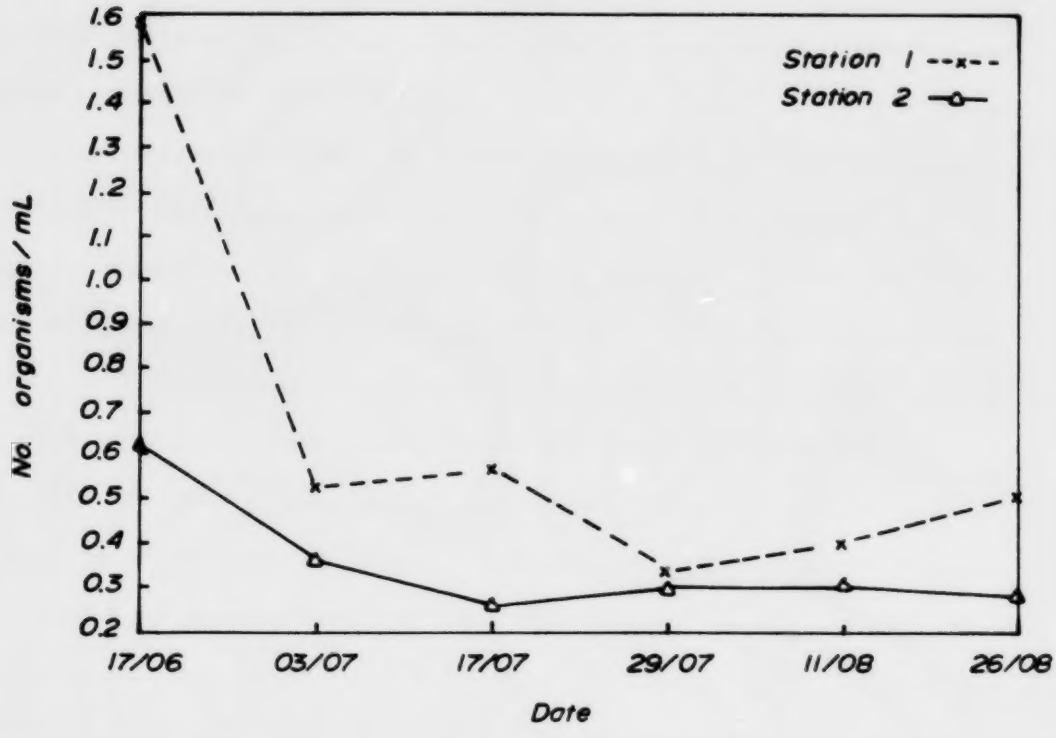
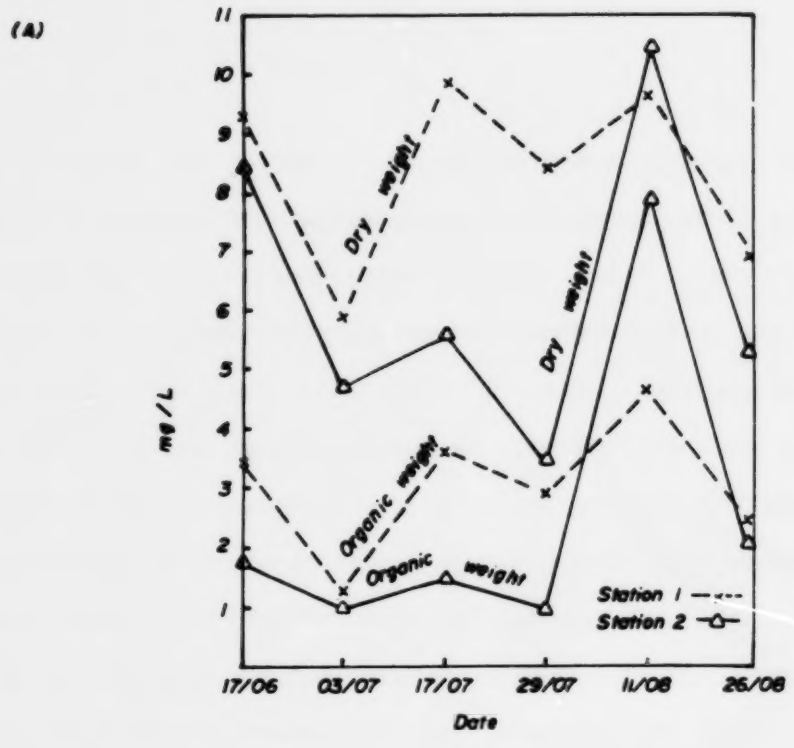


Fig. 11 Abundance of zooplankton at stations 1 and 2 in Besnard Lake in 1987.



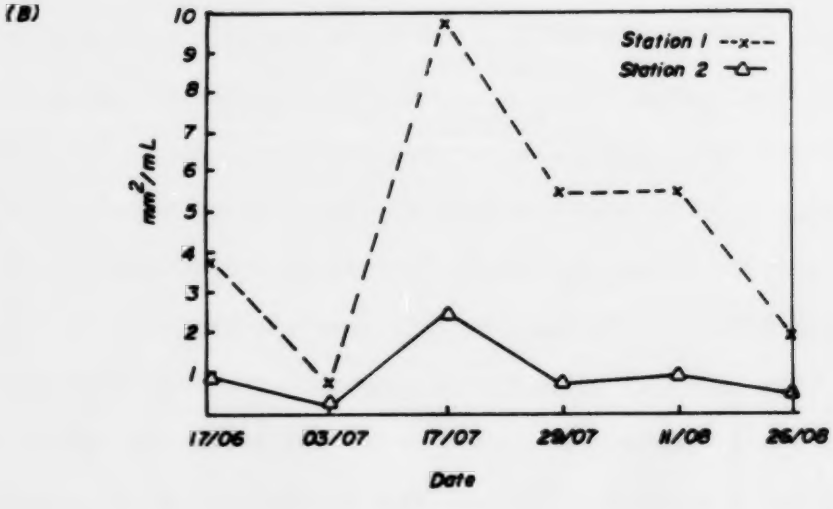


Fig. :2 Weight of netplankton (A) and amount of organic detritus (B) at stations 1 and 2 in Besnard Lake, 1987.

9.74 mm^2/ml (average 4.50 mm^2/ml ± 3.20 mm^2/ml) at station 1, and between 0.16 mm^2/ml and 2.51 mm^2/ml (average 0.92 mm^2/ml ± 0.83 mm^2/ml) at station 2 (Fig. 12B). Significantly more detritus was found at the cage culture site than in the reference bay ($p<0.02$).

5.4 Macrobenthos

On July 17, 1987 a large Ekman dredge (covering 500 cm^2 of bottom area) was used to collect macrobenthos from the culture site (station 1) and the reference site (station 2). Of the five samples taken from station 1 (depths, 2.5 - 3.8 m), three contained macrobenthos, which included chironomids, oligochaetes, Ceratopogonidae and sphaeriids. The standing crop of macrobenthos based on the three samples that contained organisms was 300 organisms/m^2, or 1.98 g wet weight/m^2.

Three dredges were obtained from station 2, giving a standing crop of 380 organisms/m^2, or 2.16 g wet weight/m^2. In addition to those organisms found at Station 1, nymphs of the mayfly Hexagenia, larvae of Dreodytes (Dytiscidae), leeches and the amphipod Gammarus were found in the bottom samples taken from station 2.

The standing crops of macrobenthos from these two sites (19.8 and 21.6 kg/ha) are only about 1/5 of the whole lake average of 97 kg/ha reported by Chen (1974). However, the sample size is too small to make a meaningful comparison between sites or with previous measurements.

6. DISCUSSION

6.1 Between Station Differences in Measured Variables

Of the dozen water quality related variables monitored, statistically significant differences between the cage culture and the reference sites were found only in under water light attentuation coefficients and the amount of particulate detritus. Although not statistically significant, the cage culture site had noticeably smaller Secchi disc transparency and higher concentrations of plankton and chlorophyll *a*. Whether these differences are directly related to the cage culture operation is uncertain at this point, because observations made so far are limited both in number and duration. Also, with only one reference site being measured, natural (background) variations within the lake cannot be properly assessed. However, most studies on the impact of trout cage culture in the literature also recorded increases in the concentrations of suspended particulates and plant nutrients near the culture site (see Beveridge 1984).

Significant differences detected in the rates of under water light attenuation, but not in Secchi depths, between the two stations indicate that the former is more sensitive than the latter as a measure of water transparency. Aside from light absorbing dissolved colored substances, water transparency is determined by the number and kind of suspended particles present in the water column (Edmondson 1980).

The higher turbidity and, hence, the greater subsurface light attenuation coefficients (averaged 1.16/m) and smaller Secchi depths (averaged 1.97 m) at the culture site is apparently due to the presence

of more suspended particulates (plankton and detritus). A simple correlation analysis between the measured variables (Table 2) indicates that subsurface light attenuation coefficient is highly correlated with Secchi depth, and that particulate detritus, phytoplankton and chlorophyll *a* concentrations are the three most important factors that determined the turbidity of the water in this lake. Further analysis using the stepwise multiple regression technique, suggests that only chlorophyll *a* (an index of phytoplankton biomass) and detritus concentrations are more important, explaining respectively 48% and 21% of the total variance of the under water light extinction (the multiple regression equation is: $K=0.7957 + 0.0336$ (detritus) $+ 0.0191$ (chla); $r=69\%$, $p<0.05$.

The fact that highly significant differences between the two stations were found only in the abundance of particulate detritus but not in the standing crop of plankton suggests that the former is a more direct measure of the immediate impact of intensive cage culture operations on water quality. This is not surprising, since cage culture operations provide an abundant supply of suspended solids from surplus feed and faecal material. Furthermore, activity of the caged fish enhances the resuspension of bottom material.

Lack of significant differences between the two stations in concentrations of the plant nutrients (see Table 2) should not lead to the conclusion that there was no additional input of nutrients into the lake from the cage culture site. In fact, the opposite is true (see next section). The reason for the insignificant difference is

Table 2. Simple correlation matrix of water turbidity related variables (both stations 1 and 2 combined), Besnard Lake, 1987.

Variables		V1	V2	V3	V4	V5
V2	r	-0.8114				
	n	12				
	p	0.0014				
V3	r	0.6187	-0.4454			
	n	11	11			
	p	0.0424	0.1698			
V4	r	-0.4091	0.5319	0.1987		
	n	11	11	12		
	p	0.2116	0.0922	0.5358		
V5	r	0.5664	-0.6270	0.2241	-0.4064	
	n	13	13	12	12	
	p	0.0436	0.0218	0.4837	0.1899	
V6	r	0.6908	-0.8723	0.3614	-0.3488	0.6197
	n	13	13	12	12	14
	p	0.0089	0.0001	0.2483	0.2664	0.0181

V1 -subsurface light attenuation coefficient; V2 - Secchi disc transparency; V3 -particulate detritus; V4 -zooplankton standing crop; V5 -phytoplankton standing crop; V6 - concentration of chlorophyll a.
r -correlation coefficient; n - number of measurements; p -probability of chance. Probabilities of 0.05 or less are generally considered significant, implying a relationship between the two variables.

probably that the number of fish raised was relatively small and the culture duration short (50 000 stocked on May 21). Based on a survival rate of 88% and an average individual weight of 200 g (derived from Ivanochko 1987), about 8.8 tonnes of trout would have been produced in October. At a food conversion ratio of 1.5:1, each tonne of trout would potentially release 17.7 kg of phosphorus to the environment (Beveridge 1984). According to these figures, between May and October only 156 kg of phosphorus would have been released from the culture site. Morecever, the dissolved nutrients were released in a period of six months and were probably absorbed quickly by the phytoplankton (hence more were present at the culture site).

6.2 Impact of Cage Culture on Water Quality

Intensive trout cage culture operations will inevitably discharge additional nutrients into the surrounding environment. A detailed study in Poland indicated that for every kilogram of marketable trout produced, the lake was enriched by 0.75 kg carbon, 0.023 kg phosphorus and 0.10 kg nitrogen (Penczak et al. 1982). In more general terms, the input of phosphorus from cage culture may range from 10.2 kg to 32.7 kg/tonne of trout produced, depending on types of feed used and the food conversion ratio (Beveridge 1984). The comparable input figures for nitrogen are generally between 75 to 95 kg (Hakanson 1986).

An increase in nutrient loading, particularly that of phosphorus, to a water body and the resultant eutrophication has been a major concern for water quality management (OECD 1982). The impact of cage culture operations on the environmental quality of a lake depends

on the size of the operation and the morphometric and hydrologic characteristics of the lake and its watershed, as well as its existing trophic state. The maximum allowable size of an operation can be expressed in terms of a lake's carrying capacity, which can be defined by a certain water quality objective. One of the guidelines contained in the recently approved Saskatchewan Aquaculture Policy attempts to address this concern (Saskatchewan Fisheries Branch 1988).

The trophic state of a lake can be evaluated using measurements of total phosphorus, chlorophyll *a* and Secchi depth (OECD 1982). Of these three variables measured from Besnard Lake, only the maximum concentration of chlorophyll *a* in the euphotic zone can be directly used to assess its trophic state, using published classification systems. According to the OECD open boundary and probabilistic system, the peak chlorophyll *a* concentration of 19.60 mg/m^3 indicates that chances of the west basin of Besnard Lake being classified into the various trophic categories are: mesotrophic, 58%; eutrophic, 32%; hypertrophic, 9%; and oligotrophic, 1%. This means that the basin is definitely mesotrophic and, at times, may even be eutrophic.

The impact of additional phosphorus input from cage culture operations can be assessed by using water quality management models already in the literature. Of the many models available, the Vollenweider-OECD eutrophication modelling approach is adopted here because of its simplicity and universality (Jones and Lee 1986, OECD 1982).

Based on the correlation equation for maximum chlorophyll concentrations and normalized phosphorus loadings (OECD 1982) and the estimated hydraulic load of the lake, the existing annual mean inflow of total phosphorus to the west basin of Besnard Lake is estimated to be 177 mg/m³, or 4 098 kg/yr (see Appendix 5 for details of calculation). This represents an annual total phosphorus loading of 8.4 mg/m² of watershed, which seems reasonable in view of the type of watershed Besnard Lake drains and the published phosphorus loading data: The annual export of total phosphorus from forests is generally in the order of 11.7 mg/m² on sedimentary and 4.9 mg/m² on granitic watersheds (Likens 1975). Although Besnard Lake is located on the edge of the Precambrian Shield, its west basin drains mainly forest watersheds in the sedimentary region through the Mercer River.

From the calculated loading, average inlake concentration of total phosphorus in the west basin of Besnard Lake is calculated to be 40 mg/m³. Calculations using annual mean concentration of chlorophyll a of 6.724 mg/m³ (estimated from the maximum chlorophyll concentration) and the updated Vollenweider-OECD normalized phosphorus loading - chlorophyll response relationship (Jones and Lee 1986) produced almost identical figures for loading and average concentration.

The impact of the phosphorus (156 kg) discharged into the basin from the first year of operation can now be assessed in terms of increases in average inlake concentration of total phosphorus, annual mean chlorophyll, or maximum chlorophyll concentrations. Results of the calculations indicate that with the additional total phosphorus loading

from the cage culture, mean annual concentration of total phosphorus would be expected to increase from the current level of 40 mg/m³ to 42 mg/m³. Within 1.4 to 2.4 years, annual mean and maximum chlorophyll concentrations would be expected to increase from the present levels of 6.7 mg/m³ and 19.60 mg/m³ to 7.3 mg/m³ and 20.70 mg/m³, respectively (Appendix 5). These changes will increase the chance of the basin being classified as eutrophic from 32% to 37% and as hypereutrophic from 9% to 11%. On the other hand, the chance of staying mesotrophic will diminish to 52% from the current 58%. These changes may not be significant, but the fact that eutrophication is occurring due to cage culture is of particular concern. Therefore, regular monitoring of certain water quality parameters in conjunction with cage culture operations is necessary to detect trends in water quality changes.

Section B.2.d of the Saskatchewan Aquaculture Policy states:

"Proposals for cage culture operations on lakes with total phosphorus concentrations over 30 mg/m³ will be referred to Saskatchewan Environmental and Public Safety for more detailed evaluation."

It is not clear whether the total phosphorus concentrations here mean average annual or summer concentrations. In any case, the current total phosphorus concentrations (either the estimated average annual concentration or mean summer value) in the west basin of Besnard Lake have already exceeded this criterion. Therefore, calculation of the carrying capacity of the lake for cage culture will be made according to another guideline (Section B.2.c) which states:

"...In order to prevent deterioration of water quality, the allowable increase in total phosphorus concentration in lakes will be 10% above the pre-aquaculture level."

Various Vollenweider-OECD empirical equations dealing with relationships between maximum chlorophyll concentrations and phosphorus loadings, as well as inlake phosphorus concentrations and loadings (OECD 1982, Jones and Lee 1986) were used to calculate the carrying capacity of Besnard Lake. The Vollenweider-OECD approach is selected mainly because of its simplicity and universality. However, if appropriate input data are available, other models can be used (see Beveridge 1984).

Based on the calculated average annual inlake phosphorus concentration of 40 mg/m^3 and allowing a 10% increase over this level, the carrying capacity of the west basin of Besnard Lake is estimated to be 23 tonnes of rainbow trout (see Appendix 5 for details of calculation). If only 5% increase above the pre-culture level is allowed, the carrying capacity is reduced to 11.5 tonnes of fish.

Moderate eutrophication resulting from controlled cage culture operations may benefit the fishery. It has been demonstrated that fishes generally respond to increasing eutrophication with an increase in yield in a predictable way. Measurements of total phosphorus (Hanson and Leggett 1982) and normalized phosphorus loading (Lee and Jones 1985, in Jones and Lee 1986) have been found to be good predictors of overall fish yield. According to the normalized phosphorus loading/fish yield relationship developed by Lee and Jones (1985), the calculated normalized phosphorus loading to Besnard Lake (40 mg/m^2) corresponds to

a fish yield of about 2.7 kg/ha/yr (close to the 3.0 kg/ha/yr of total harvest from commercial and sport fisheries estimated by Chen, 1974). As calculated earlier, the first year of cage culture in Besnard Lake would have increased the normalized phosphorus loading to about 42 mg/m^3. The corresponding increase in overall fish yield is negligible.

While changes in overall fish yield with increasing eutrophication can be calculated, the response of individual species is less quantifiable. Although a fish species may respond favorably to progressive eutrophication, there is some threshold level, beyond which the response becomes negative. This threshold level on the trophic scale varies with individual species according to tolerances to altered environment, adaptabilities to new habitat and forage base, as well as reproductive behavior (Leach et al. 1977). Of the economically important fishes in Besnard Lake, walleye, perch, pike, and suckers are more tolerable than whitefish to progressive eutrophication, and thus would benefit more from cage culture operations. The whitefish, which requires clean, sand and gravel bottom for spawning may suffer if eutrophication leads to heavy deposition of organic matter. Penczack et al. (1982) reported that the native whitefish in a small, mesotrophic lake in Poland ceased to reproduce during the period of trout cage culture, presumably due to loss of suitable spawning habitats. However, being much larger in area and with much smaller input of phosphorus from cage culture, similar events are unlikely to occur in Besnard Lake.

All the above estimates must be interpreted with caution, because large uncertainties may be associated with using models developed with data obtained elsewhere. The risk of introducing gross errors is further increased if inadequate input data are used. Therefore, it is imperative that every attempt should be made, within available resources, to obtain high quality input data. Also, regular monitoring of pertinent water quality variables in connection with cage culture is needed.

Of the input data used in this study, a good measurement of the maximum concentration of chlorophyll can be obtained relatively easily with low costs. Average annual concentrations of total phosphorus and chlorophyll are seldom available for Saskatchewan lakes, because high frequency sampling throughout the year is required to obtain them. Fortunately, these variables can be estimated indirectly from the maximum concentration of chlorophyll. Morphometric characteristics of the lake (water area, volume, mean depth) and hydrologic data (inflow-outflow or hydraulic load from the watershed needed to calculate water residence time) if not already available from previous surveys can only be estimated indirectly from other information with unknown accuracy. Use of inaccurate estimates of the hydraulic load and water residence time is probably the most serious source of errors in using these models. Unfortunately, hydrologic data of watersheds are seldom readily available for most Saskatchewan lakes.

7. CONCLUSIONS AND RECOMMENDATIONS

The intensive cage culture operation in the west basin of Besnard Lake produced an estimated 8.8 tonnes of rainbow trout in 1987. The most significant and immediate effect of the operation was an increase in water turbidity, which was attributable to higher concentrations of suspended detritus and algal biomass.

Besnard Lake is already mesotrophic and, at times, may even be eutrophic. Its calculated average annual total phosphorus concentration has already exceeded the maximum allowable concentration of 30 mg/m^3 recommended for cage culture (see the Saskatchewan Aquaculture Policy).

An estimated 156 kg of phosphorus was discharged from the cage culture site during the first year of operation. The overall impact of this additional phosphorus input into the west basin of Besnard Lake on water quality and native fish populations is negligible, but can nevertheless be quantified.

Allowing a 10% increase in the total phosphorus concentration over the current level, the carrying capacity of the west basin of Besnard Lake is estimated to be 23 tonnes of rainbow trout per year. If only a 5% increase is allowed, the carrying capacity is reduced to 11.5 tonnes, which is closer to the first year's production.

Based on the findings of this study, the following is recommended:

1. Periodic monitoring programs should be conducted in order to detect changes in water quality due to cage culture operations.

2. Variables measured should include: status of native fish populations, plankton, maximum concentration of chlorophyll *a*, oxygen and temperature profiles, pH, Secchi disc transparency, and plant nutrients.

3. The maximum concentration of chlorophyll *a* should be used as primary input datum to estimate the expected total phosphorus input and carrying capacity of the lake (see Appendix 5 for details). Also, chlorophyll is preferred over phosphorus for setting water quality objectives for the determination of carrying capacity of lakes.

4. Cage culture in the west basin of Besnard Lake may be allowed to continue with the carrying capacity set at 12 tonnes of marketable rainbow trout; furthermore, monitoring programs such as mentioned above should be conducted in 1989, and again in 1992. If the lake is to be used for experimental management studies, the carrying capacity can be increased.

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Appendix 1. Temperatures (C) and concentrations of dissolved oxygen (mg/l) , Besnard Lake, 1987.

Depth	June 10				June 17				July 3			
	Station 1		Station 2		Station 1		Station 2		Station 1		Station 3	
(m)	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
0.0	14.5	9.2	15.5	9.4	17.0	8.8	18.0	8.9	20.5	8.7	19.8	7.9
0.5									20.0	8.6		
1.0	14.0	9.0	15.5	9.4	17.0	8.7	18.0	8.8	20.0	8.2	19.0	7.7
1.5												
2.0	13.5	9.0	15.0	9.4	17.0	8.7	18.0	8.8	19.5	8.2	19.0	7.6
2.5												
3.0	13.0	8.6	14.5	9.3	16.8	8.7	17.8	8.8	19.0	7.8	19.0	7.3
4.0												
5.0			14.0	8.6							18.8	7.0
6.0											18.7	6.5
7.0											18.5	6.3
8.0											17.0	4.8
9.0											16.7	4.2
10.0											16.2	3.5
11.0											16.0	3.3
12.0											15.5	3.0
13.0											15.0	2.4
14.0											14.5	2.2
15.0												
15.5												
Air temp	17.0		17.0		19.0		19.5		26.0		23.0	

Appendix 1 (continued). Temperatures (C) and concentrations of dissolved oxygen (mg/l), Besnard Lake, 1987.

July 17						July 29					
Station 1		Station 2		Station 3		Station 1		Station 2		Station 3	
Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
19.2	8.6	19.0	9.3	19.0	9.0	22.0	8.7	22.2	9.8	21.5	9.7
19.0	7.5	19.0	9.3			22.0	8.6	22.0	10.0	21.5	9.7
19.0	7.5	19.0	9.3	19.0	8.9	22.0	8.6	21.7	10.0	21.5	9.7
19.0	7.6	19.0	9.3			22.0	8.6	21.5	9.7	21.5	9.7
19.0	7.7	19.0	9.4	18.9	8.9	22.0	8.5	21.5	9.6	21.3	9.6
19.0	7.8	18.8	9.3	18.8	9.0	21.0	7.7	21.5	9.6	21.0	9.6
19.0	8.1	18.8	9.3	18.8	9.0	20.5	2.2	21.3	9.4	21.0	9.4
				18.8	9.0			21.2	7.8	20.5	9.1
										20.0	8.4
				18.5	8.9					19.5	7.3
				18.5	8.7					19.0	5.9
				18.5	8.6					18.5	5.3
				18.5	8.3					18.0	4.7
				18.0	5.9					17.5	3.5
				17.7	5.1					17.0	2.4
				16.8	3.1					16.5	1.4
				16.0	2.0					15.5	0.5
				15.0	0.9					14.0	0.1
										13.8	0.1
19.0		17.0						25.0			

Appendix 1 (continued). Temperatures (C) and concentrations of dissolved oxygen (mg/l), Besnard Lake, 1987.

August 11						August 26					
Station 1		Station 2		Station 3		Station 1		Station 2		Station 3	
Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
17.2	8.5	18.0	8.7	18.0	8.1	18.0	9.4	18.0	9.6	17.0	9.1
17.2	8.5	18.0	8.7			18.0	9.5	18.0	9.6		
17.2	8.5	18.0	8.6	18.5	8.1	17.7	9.5	18.0	9.6	17.0	9.1
17.2	8.3	18.0	8.6			17.6	9.5	17.5	9.6		
17.2	8.2	18.0	8.6	18.5	8.1	17.5	9.5	17.0	9.8	17.0	9.0
17.0	8.1	18.0	8.6			17.5	9.5	17.0	9.5		
17.0	8.0	17.8	8.5	18.5	8.0	17.5	9.5	16.5	9.0	17.0	8.8
								16.0	7.2		
				18.5	7.9					16.7	8.7
				18.5	7.9					16.5	8.4
				18.5	7.8					16.5	8.3
				18.5	7.8					16.5	8.1
				18.5	7.7					16.5	7.4
				18.5	7.6					16.0	7.4
				18.5	7.5					16.0	7.1
				18.3	6.2					16.0	6.9
										16.0	6.7
										16.0	6.0
										16.0	5.6
										15.8	4.2
										15.0	1.4
		14.0						21.0		22.0	

Appendix 2. Selected physical characteristics of Besnard Lake, 1987.

Date	Station 1				Station 2				Station 3			
	pH		K	SDT	pH		K	SDT	pH		K	SDT
	Surface	Bottom	(/M)	(M)	Surface	Bottom	(/M)	(M)	Surface	Bottom	(/M)	(M)
June 10	7.90	NA	1.14	2.30	8.12	NA	0.92	3.00	NA	NA	NA	NA
17	8.01	7.94	0.90	2.80	7.97	7.97	0.72	3.00	NA	NA	NA	NA
July 3	8.20	8.11	0.93	2.40	NA	NA	NA	NA	8.39	7.25	1.22	NA
17	8.22	8.04	1.31	1.50	8.88	8.85	1.05	1.58	NA	NA	0.99	1.53
29	8.52	8.11	1.34	1.42	9.09	9.08	1.13	1.42	NA	NA	1.00	1.45
August 11	7.89	7.94	1.38	1.54	8.22	8.18	1.21	NA	NA	NA	1.25	NA
26	8.47	8.55	1.10	1.75	8.60	8.30	1.02	1.80	NA	NA	1.14	2.30
Mean	8.11	8.08	1.16	1.97	8.32	8.31	1.01	2.16	NA	NA	1.12	2.03
SD	0.25	0.17	0.19	0.55	0.50	0.50	0.17	0.78	NA	NA	0.12	0.66

Notes: K = vertical light extinction coefficient, calculated from measurements made in 0 to 3 M depths
SDT = Secchi disc transparency
NA = data not available
SD = standard deviation

Appendix 3. Standing crop (1000 cells/l) of phytoplankton, Besnard Lake, 1987. Station 1 (cage culture site)

DATE	Jun 10	Jun 17	Jul 3	Jul 17	Jul 29	Aug 11	Aug 26
CHLOROPHYCEAE(GREEN ALGAE)	10.48	6.9	21.8	4.8	13.52	29	14.5
Actinastrum gracilimum	0	0	0	1.3	0	0	0
Ankistrodesmus falcatus	0	0	0	0	1.6	1.2	1.2
Arthrodesmus	0	0	0	0	0	0	0
Botryococcus braunii	0	0	3	0	2	4	0
Closterium	0	0	0	0	0.04	0.2	0.1
Coelastrum microporum	0.8	0	1	0	2	0	0
Cosmarium	0	0	0	0.2	0.4	1	0.4
Crucigenia quadrata	0	0	0	0.4	0	1	0
Crucigenia tetrapedia	0	0	0	0	0	1	0
Dictyosphaerium simplex	1.8	0	1.2	0	1.4	2.6	3.2
Elakatothrix gelatinosa	0.4	0.1	0	0	0.2	0	0
Euastrum	0	0	0	0	0	0	0
Kirchneriella elongata	0	0	0	0	0	0	0
Oocystis borgei	0.2	1.4	1.2	0.3	1.4	1	1.4
Oocystis solitaria	0	0.8	0	0	0	1	0
Pandorina morum	0	0	0	0	0	2	1.2
Pediastrum boryanum	2.4	1.8	2	1.2	2	1.8	0
P. duplex	1.6	1.2	1.6	0	1.4	1.8	2
P. obtusum	0	0	1	0	0	0	0
P. tetras	0	0	0	0	0	0	0
Scenedesmus acuminatus	0	0	3.4	0	0	1.4	0
S. bijuga	0.8	0.8	2.6	0	0	1	1
S. ecornis	2	0	0	0	0	0	0
S. quadricauda	0.4	0	2	0.6	1	1	0.8
Selenastrum gracillimum	0	0	2.4	0	0	0	2
Staurastrum	0.08	0.8	0.4	0.8	0.08	1	1.2
CHRYSOPHYCEAE(GOLDEN ALGAE)	4.4	5	4	6	4.4	5.4	8
Dinobryon sertularia	3.4	2.2	0	1	0	1.8	2.8
D. sociale	0	0	0	0.8	0	0	0
Mallomonas acaroides	1	0.8	1.2	1.2	1.4	1	1.4
Synura uvella	0	2	2.8	3	3	2.6	3.8

Appendix 3 (continued). Standing crop (1000 cells/l) of phytoplankton, 1987
Station 1 (cage culture site)

DATE	Jun 10	Jun 17	Jul 3	Jul 17	Jul 29	Aug 11	Aug 26
BACILLARIOPHYCEAE (DIATOMS)	12.84	13.84	10.64	11.08	8.96	13	12.08
Asphora	0	0	0	0	0.04	0	0.04
Asterionella formosa	1.2	2	1.4	1.2	1.2	1.8	2
Cocconeis pediculus	0.04	0.08	0	0.08	0	0.08	0.04
Diatoma	0	0	0	0	0	1.6	0
Fragilaria crotonensis	3	4.2	2.8	2.2	2.6	1.4	1.8
Gomphonels herculeana	0.04	0.04	0	0.04	0	0.04	0.04
Gyrosigma	0.04	0	0	0	0	0	0
Melosira granulata	4.8	4.8	3.4	4.6	4	4.8	3.6
Navicula	0.08	1	0.6	0.4	0.2	0.6	0.8
Nitzschia acicularis	0	0	0	0	0	0	0
Rhopalodia gibba	0.04	0.08	0.04	0.08	0.04	0.04	0.08
Surirella ovalis	0	0	0	0	0	0	0
Stauroneis	0	0.04	0	0	0	0.04	0.08
Stephanodiscus astrea	2	1	0.8	0.8	0.8	1.2	0
Synedra acus	0.8	0.1	0.8	0.08	0	0.4	0.8
S. ulna	0	0.5	0.4	0.2	0.08	1	1
Tabellaria fenestrata	0.8	0	0.4	1.4	0	0	1.8
EUGLENOPHYCEAE (EUGLENOIDS)	0.08	0.24	0.36	0.12	0.08	0.48	1.2
Euglena	0	0.04	0.04	0.04	0.04	0.08	0.4
Phacus	0.08	0.2	0.08	0.08	0.04	0.4	0.8
DINOPHYCEAE	0.2	0.12	0.14	0.2	0.08	0.5	0.04
Ceratium hirundinella	0.08	0.08	0.1	0.08	0.08	0.1	0.04
Gymnodinium	0.04	0.04	0.04	0.04	0	0.4	0
Dinoflagellate cysts	0.08	0	0	0.08	0	0	0
MYXOPHYCEAE(BLUE-GREEN)	27.1	52.5	52.9	82	60	83.5	65.6
Anabaena flos-aqua	1.4	6	9	16	12	12	16
Aphanizomenon flos-aquae	3.4	3.5	5	7.2	4	8.4	3.8
Aphanocapsa	0	0	0	0	3	0	3.4
Aphanothece	0	4.8	0	4.2	3	3.6	0
Chroococcus limneticus	1.4	1.8	1.4	3.2	1.5	4	2.6
Coelosphaeriumkuetzingianum	5.5	5.8	4.5	8.4	5	7.5	8
Coelosphaerium naegelianum	6.2	7.6	6.5	12	3.5	14	10
Gomphosphaeria aponina	0	1	0	1	0	0	1.8
Merismopedia glauca	0	0	1.5	0	0	0	0
Microcystis aeruginosa	8	22	25	30	28	34	20
Oscillatoria	1.2	0	0	0	0	0	0
UNIDENTIFIED							
Flagellates	1.2	3	2	3.8	2.2	4	3.6

Appendix 3 (continued). Standing crop (1000 cells/l) of phytoplankton, 1987.
Station 7 (reference site).

DATE	Jun 10	Jun 17	Jul 3	Jul 17	Jul 29	Aug 11	Aug 26
CHLOROPHYCEAE(GREEN ALGAE)	8.98	6.74	18.28	16.6	14.52	21.33	19.72
Actinastrum gracilimum	0	0	0	0	0	0	0
Ankistrodesmus falcatus	1	0	1	1.8	0.8	1	1
Arthrodesmus	0	0	0	0	0	0	0
Botryococcus braunii	0	0	1.8	1.4	0	4.6	0
Closterium	0	0	0.08	0	0.4	0.08	0.04
Coelastrum microporum	0	1	1.6	1.8	1	0	0
Cosmarium	0.08	0	0.04	0.8	0.04	0.05	0.08
Crucigenia quadrata	0.2	0	0.2	0	0	0	0
Crucigenia tetrapedia	0	0	0	0	0.8	0	0.8
Dictyosphaerium simplex	0	0	2.4	1.6	1.2	1.8	2.8
Elakatothrix gelatinosa	0	0	0.08	0.2	0	0	0.8
Euastrum	0	0	0.08	0.2	0	0	0
Kirchneriella elongata	1	0	1.8	0.8	0	0	0
Oocystis borgei	0.5	0.2	0	2.2	0.8	1	1.2
Oocystis solitaria	0	0.04	0	0	0.08	0.8	0.8
Pandorina morum	0	0	0	0	0	0	1.4
Pediastrum boryanum	2	1.8	2.4	0	1.8	3.2	3.2
P. duplex	1.2	1	0	1.2	2.4	2.6	2.4
P. obtusum	1	0	0	0	1.2	1	0
P. tetras	0	0	0	0	0	0.2	0
Scenedesmus acuminatus	0	0	2.8	0.8	0	0	1.8
S. bijuga	0.8	1.4	1	1.4	0.8	1	0
S. ecornis	0	0	0	0	1.2	0.8	0
S. quadricauda	0.8	0.8	1	1	1.2	0.8	1.2
Selenastrum gracillimum	0	0	1.8	1	0	1.4	1.2
Staurastrum	0.4	0.5	0.2	0.4	0.8	1	1
CHRYSOPHYCEAE(GOLDEN ALGAE)	5.4	6	6.4	5.9	4.2	4.8	5
Dinobryon sertularia	4.2	2.6	1.2	0.8	0	0	1
D. sociale	0	0	0	0	0	0	0
Mallomonas acaroides	1.2	0.6	1.4	1.6	0.8	1	1.2
Synura uvella	0	2.8	3.8	3.5	3.4	3.8	2.8

Appendix 3 (continued). Standing crop (1000 cells/l) of phytoplankton, 1987.
Station 2 (reference site).

DATE	Jun 10	Jun 17	Jul 3	Jul 17	Jul 29	Aug 11	Aug 26
BACILLARIOPHYCEAE (DIATOMS)	15.34	10.56	8.68	10.02	7.58	8.12	10.08
Amphora	0.04	0	0	0	0.02	0	0.08
Asterionella formosa	2	1.4	1.8	1.4	1.2	1.4	1.8
Cocconeis pediculus	0.04	0	0	0.08	0	0.04	0
Diatoma	0	0	0	0	0	0	0
Fragilaria crotonensis	4.5	3.2	1.8	1	1.8	2	2.4
Gomphoneis herculeana	0.08	0	0	0	0	0	0
Gyrosigma	0	0	0	0	0	0	0
Melosira granulata	5	4	2.6	5	3.2	3.4	4.2
Navicula	0.2	0	0.08	0.1	0.08	0.4	0.4
Nitzschia acicularis	0	0	0	0	0	0	0.04
Rhopalodia gibba	0.04	0	0	0	0	0.08	0.08
Surirella ovalis	0	0	0	0.04	0	0	0
Stauroneis	0.04	0	0	0	0	0	0.6
Stephanodiscus astrea	2	1	1	0.8	0.2	0.4	0
Synedra acus	0.2	0.08	0	0	0.2	0.2	0.08
S. ulna	0	0.08	0.4	0.2	0.08	0.2	0.4
Tabellaria fenestrata	1.2	0.8	1	1.4	0.8	0	0
EUGLENOPHYCEAE (EUGLENOIDS)	0.04	0.04	0.04	0.08	0.04	0.08	0.12
Euglena	0	0	0.04	0.04	0.04	0.08	0.04
Phacus	0.04	0.04	0	0.04	0	0	0.08
DINOPHYCEAE	0.08	0.08	0.48	0.24	0.24	0.44	0.88
Ceratium hirundinella	0.04	0.04	0.4	0.2	0.2	0.4	0.8
Gymnodinium	0	0.04	0	0	0.04	0.04	0.08
Dinoflagellate cysts	0.04	0	0.08	0.04	0	0	0
MYXOPHYCEAE (BLUE-GREEN)	35.4	53.2	60.6	53.2	79	81.2	53.5
Anabaena flos-aqua	2.6	10	8	10	16	14	18
Aphanizomenon flos-aquae	0	4.5	6.2	4.5	4.8	1.2	0
Aphanocapsa	0	0	0	0	4.8	6.2	4.2
Aphanothece	0	4	3.5	4	2.4	2	0
Chroococcus limneticus	0.8	2.6	2	2.6	3.2	3.4	3.2
Coelosphaerium kuetzingianum	8	4.6	7.5	4.6	8.4	10	6.4
Coelosphaerium naegelianum	10	5.5	8.4	5.5	12	14	8.5
Gomphosphaeria aponina	0	0	0	0	0	0	1.2
Merismopedia glauca	0	0	1	0	0	2.4	0
Microcystis aeruginosa	14	22	24	22	26	28	12
Oscillatoria	0	0	0	0	1.4	0	0
UNIDENTIFIED							
Flagellates	2	3	2.4	3	4.6	3.2	4.2

Appendix 4. Standing crop of zooplankton (no. organisms/L) in Besnard Lake, 1987
Station 1

Date	June 17	July 3	July 17	July 29	Aug 11	Aug 26
COPEPODA	68	21	8	20	12	12
Cyclopoida	57	12	8	20	12	8
Calanoida	11	9	0	0	0	4
Nauplius	53	36	33	70	45	25
CLADOCERA	10	18	3	2	3	3
Bosmina	1	0	1	0	0	1
Chydorus	5	9	1	1	0	0
Daphnia dubia	4	9	0	0	0	0
Diaphanosoma	0	0	1	1	3	2
Holopedium gibberum	0	0	0	0	0	0
SUM	131	75	44	92	60	40
ROTIFERA						
Asplanchna	1	18	0	1	3	3
Brachionus	0	1	1	0	0	0
Chromogaster	0	0	9	0	0	4
Conochilus	8	12	3	0	9	2
Kellicottia longispina	293	24	0	6	4	0
Keratella canadensis	5	6	1	0	0	1
K. cochlearis	1030	373	245	139	248	195
Monostyla	0	0	44	3	7	146
Pleurotrocha	19	2	5	0	0	0
Polyarthra	99	18	199	87	50	69
Trichocerca	4	27	23	12	19	0
Unidentified	0	0	0	0	1	20
SUM	1459	454	530	248	341	472
Total	1590	529	574	340	401	512

Appendix 4 (continued). Standing crop of zooplankton (no. organisms/l) in Flesnard 1987. Station 2

Date	June 17	July 3	July 17	July 29	Aug 11	Aug 26
COPEPODA	40	16	9	8	9	5
Cyclopoida	29	8	7	5	6	4
Calanoida	11	8	2	3	3	1
Nauplius	39	34	44	32	37	27
CLADOCERA	96	18	2	9	10	2
Bosmina	7	0	0	0	0	0
Chydorus	1	9	1	0	0	0
Daphnia dubia	104	9	1	0	1	0
Diaphanosoma	0	0	0	9	9	2
Holopedium gibberum	4	0	0	0	0	0
SUM	165	68	55	49	56	34
ROTIFERA						
Asplanchna	1	8	4	0	0	1
Brachionus	0	0	0	0	0	0
Chromogaster	0	24	5	14	4	2
Conochilus	14	17	0	0	6	8
Kellicottia longispina	131	10	0	0	3	1
Keratella canadensis	4	6	0	4	1	0
K. cochlearis	247	180	138	160	149	119
Monostyla	0	0	0	21	14	49
Pleurotrocha	11	17	7	0	0	0
Polyarthra	44	18	23	37	43	39
Trichocerca	4	12	26	16	19	23
Unidentified	0	0	0	0	3	8
SUM	456	292	203	252	242	250
Total	621	360	258	301	298	284

Appendix 5. Details for calculations of total phosphorus loadings and the carrying capacity of the west basin of Besnard Lake, using the Vollenweider - OECD modelling approach (Jones and Lee 1986, OECD 1982).

Morphometric and hydrologic characteristics of the lake and its watershed:

	West basin	Whole lake
Water area (A_w), km^2	38	177
Volume (V), x $10^6 m^3$	281	1402
Mean depth ($\bar{Z}$), m	7.4	7.9
Watershed area (A_w), km^2	486	806
Median water surplus (q), m/watershed/yr	0.04762*	0.04762*
Hydraulic load (q_s), m/lake area/yr	0.6090	0.2168
Water residence time (T_w=V/q.A_w), yr	12	37

*Derived from data presented in Gray (1964).

The primary water quality parameter: maximum concentration of chlorophyll a in the euphotic zone, [max. chl] = 19.60 mg/m^3.

Estimations of total phosphorus loadings, using the empirical formula:

$[\text{max. chl}] = 0.74 ([\bar{P}]_i / 1 + \sqrt{T_w})^{0.89}$, where [max. chl] and T_w are defined as above and $[\bar{P}]_i$ is the average annual inflow concentration of total phosphorus, $(L_{<P>}/q_s)$, in mg/m^3. $L_{<P>}$ is total phosphorus loading in $g/yr/m^2$ of lake surface.

Therefore, when [max. chl] = 19.60 mg/m^3, T_w = 12 yr, the corresponding $[\bar{P}]_i$ = 177 mg/m^3, and $L_{<P>}$ = 177 mg/m^3 x q_s = 0.108 $g/m^2/yr$. The total annual phosphorus input into the basin is: 177 mg/m^3 x q x A_w = 4096 kg.

Calculation of the average annual inlake total phosphorus concentration from known total phosphorus loading, using the equation:

$$[\bar{P}]_\lambda = [\bar{P}]_i / (1 + \sqrt{T_w})$$
$$= 177/4.46$$
$$= 40\ mg/m^3$$

$[\bar{P}]_\lambda$ and $[\bar{P}]_i$ can also be estimated from the average annual concentration of chlorophyll a, $[\bar{chl}]$.

Since direct measurement of $[\bar{chl}]$ is not available from the present study, it has to be estimated from the equation:

$$[\text{max. chl}] = 2.60\ [\bar{chl}]^{1.06}.$$

Appendix 5 (continued)

Thus, when [max. chl] = 19.60 mg/m³, the corresponding [$\bar{chl}$] is 6.7239 mg/m³.

From Fig. 3 of Jones and Lee (1986), the above [$\bar{chl}$] corresponds to a normalized phosphorus loading of 40 mg/m³
(=($(L_{<P>}/q_s$ / (1 + $\sqrt{T_w}$), or = $[\bar{P}]_i$ / (1 + $\sqrt{T_w}$).

Therefore, $[\bar{P}]_i$ = 178 mg/m³, and the total annual phosphorus loading = 4120 kg. These values are almost identical to the estimates made from [max. chl].

Calculation of the carrying capacity of the lake:

1. Setting the water quality objective: allowing a maximum of 5% increase in the average inlake total phosphorus concentration over the pre-culture level (concentrations of maximum or average annual chlorophyll a can be used instead to set the water quality objective).

2. Estimating the allowable total phosphorus input: the above water quality objective would allow an increase of 2 mg/m³ in the average inlake phosphorus concentration. From the equation $[\bar{P}]_\lambda$ = $[\bar{P}]_i$ / (1 + $\sqrt{T_w}$), this would correspond to an increase of 8.92 mg/m³ in $[\bar{P}]_i$, and a total annual loading of 206 kg in total phosphorus.

3. Estimating the carrying capacity: Assuming a total phosphorus loading rate of 17.7 kg/tonne of fish produced from intensive culture (Beveridge 1982), the carrying capacity of the west basin of Besnard Lake is: 206/17.7 = 11.6 tonnes of marketable trout.

Response time: lakes do not respond immediately to changes in phosphorus loadings. The length of time it takes to have a change in water quality depends on the time required for the concentration of phosphorus to move halfway from the original steady-state to the new steady-state. This halfway time is called the half-life of the change in phosphorus concentrations ($t_{1/2}$), which is determined by the lake's mean depth ($\bar{Z}$) and hydraulic flushing rate (ρ = 1 / $\sqrt{T_w}$) (Dillon and Rigler 1975):

$$t_{1/2} = 0.69 / (\rho + 10/\bar{Z}).$$
$$= 0.69 / (0.082 + 10/7.4),$$
$$= 0.48,$$

and the response time is estimated as: (3-5) $t_{1/2}$ = 1.4 - 2.4 (yr).